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NOTE

THIS DOCUMENT IS TO BE USED FOR ALL FLIGHT STRUCTURES OTHER THAN THOSE WHICH INTERFACE DIRECTLY WITH THE SPACE SHUTTLE ORBITER.

JSC 14046, "PAYLOAD INTERFACE VERIFICATION REQUIREMENTS," AUGUST 1980, IS TO BE USED FOR ALL STRUCTURES WHICH INTERFACE DIRECTLY WITH THE ORBITER.

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PREFACE

This publication establishes general requirements for structural strength programs to ensure that aeronautical and space system hardware is designed and fabricated with sufficient margin of safety to assure adequate strength, service life, rigidity, and safety of personnel.

Marshall Space Flight Center (MSFC) will invoke the requirements of this publication to the extent required and consistent with program planning in the design and procurements of aeronautical and space systems and elements thereof. In each case, the extent of application of these requirements will be described specifically in the Statement of Work of the Request for Proposal (RFP) and/or contract. System contractors will be required to impose applicable provisions of this document in selected subcontracts.

This document supersedes MSFC-HDBK-505 dated June 1, 1971 in its entirety.

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CHAPTER 1: INTRODUCTION

100 SCOPE

This publication prescribes general structural strength program requirements for contracts and MSFC in-house efforts involving the design, development and fabrication of aeronautical and space systems (including experiments and payloads) and elements thereof.

101 DESIGN INFORMATION DOCUMENTS

Appendix A, "Design Information Documents," lists documents containing design information approved for use. Other documents used by the contractor in addition to those listed must be made available to MSFC upon request.

102 DEFINITIONS

For definitions of terms used in this publication, see Appendix B.

CHAPTER 2: PROGRAM REQUIREMENTS

200 GENERAL

1. The responsible design element shall establish and maintain an effective strength analysis, structural test and structural assessment program to assess and verify the structural integrity of space vehicle structural and propulsion systems. The program shall ensure that space vehicle hardware is designed and constructed to meet program requirements using the factors of safety specified herein.

2. Hardware shall be designed to minimize weight and yet resist all loads and combination of loads that may reasonably be expected to occur during all phases of fabrication, testing, transportation, erection, checkout, launch, flight, and recovery. Design criteria shall be furnished by the procuring activity. Criteria originated by the responsible design element shall be approved by MSFC prior to use.

3. The responsible design element shall show by analyses and/or tests that the hardware meets program design requirements with sufficient margin of safety to assure adequate strength, service life, rigidity, and safety of personnel at all times. The responsible design element shall submit strength analysis and qualification test reports which will verify the capability of hardware to meet design requirements with factors of safety as specified herein. Tests may be performed by the responsible design element in support of the analytical techniques and methods used in hardware design.

4. The responsible design element shall provide an assessment of the "as built" flight hardware as compared to the design and to the design mission that the vehicle is to fly. This assessment shall be accomplished using the design analysis and the qualification test results to establish the flight worthiness of flight hardware.

CHAPTER 3. STRENGTH ANALYSIS

300 GENERAL

The responsible design element shall perform strength analysis and document them so that it is clearly demonstrated that strength requirements have been fulfilled. Strength analysis reports shall be submitted to MSFC in support of the following four design reviews: PDR, CDR, DCR, and FRR. These reports shall be current with respect to loads and the design at the time of the review. Current strength analysis reports shall be available to support interim reviews.

The strength analysis reports shall be prepared in accordance with standard aerospace industry practice for flight hardware. A description of the format and content acceptable to MSFC for strength analysis reports is presented below. The contents are required in the report; however, the format may be varied to suit the particular responsible design element's own standard practices. Any significant variations should be coordinated with and approved by MSFC prior to report submittal.

301 STRENGTH ANALYSIS FOR PDR

Preliminary strength analysis reports shall be submitted to MSFC as part of the PDR data package. The PDR strength analysis shall be sufficiently detailed to assure the structural integrity of all major structure elements and the credibility of weight calculations.

302 STRENGTH ANALYSIS FOR CDR

Strength analysis reports shall be submitted to MSFC as part of the CDR data package. This report shall fully substantiate the structural integrity of each detailed part and provide the basis for stress signatures required on all drawings.

303 STRENGTH ANALYSIS FOR DCR

Strength analysis reports shall be submitted to MSFC as part of the DCR data package. This report shall include changes or additions to the CDR strength analysis data package and shall fully substantiate the structural integrity of each detailed part. The data package shall also include the evaluation of structural testing performed to certify flight worthiness.

304 STRENGTH ANALYSIS FOR FRR

Strength analysis data shall be available to support the FRR data package. These data shall include only revisions to update the strength analysis reports for the flight design configuration.

305 FORMAT AND CONTENT FOR STRENGTH ANALYSIS REPORTS

The strength analysis reports shall be prepared in accordance with standard aerospace industry practices for flight hardware; that is, the analyses shall clearly identify such items as geometric description of each component, identification of all applied loads, type of material and applicable strength allowables, environments and effects, proper identification of references for all input into the analyses, and a summary of all calculated margins of safety.

The fatigue and fracture mechanics analyses shall be included in the strength analysis reports.

CHAPTER 4. STRENGTH QUALIFICATION TEST

400 GENERAL REQUIREMENTS

Strength qualification tests are required for components designed to the static test factors of safety given in Chapter 5, except where noted. Qualification tests of the flight article design requires a separate qualification unit exactly like the flight article unless protoflight tests (see Section 403) are approved by MSFC. Fracture mechanics proof testing and fatigue testing to demonstrate cycle life are covered in Chapters 6 and 7. All test plans and requirements shall be coordinated with and approved by MSFC prior to implementation. Test results and evaluation shall be submitted to MSFC.

401 STATIC TESTS

In general, strength qualification testing shall be static. Test loads shall duplicate or envelope all flight loads and include pressure and temperature effects. When a separate qualification unit is used, the tests shall be accomplished at the yield and ultimate levels specified by the factors of safety in Chapter 5.

402 FLIGHT ARTICLE SIMULATORS

If the component to be tested is statically determinant, it may be tested as a stand-alone unit. If the component to be tested is not statically determinant, the interfacing structure through which the loads and reactions are applied to the qualification unit must be simulated in the test. The interfacing structure used in the test must simulate the stiffness and boundary conditions of the corresponding flight hardware.

403 PROTOFLIGHT TESTS

Protoflight testing and associated test factors may be accepted in lieu of static qualification testing with MSFC approval. The test factors will be limited to values which will not subject the protoflight structure to detrimental deformations beyond the elastic limit.

404 DEVELOPMENT, COMPONENT, AND SUBSCALE STRUCTURAL TESTS

Results from development, component, and subscale structural tests shall be made available to MSFC upon request.

CHAPTER 5: FACTORS OF SAFETY

500 GENERAL

The factors of safety specified herein are the minimum to be applied. Safety factors different from those specified herein must be approved by MSFC prior to use.

1. For components, or systems subjected to several missions, static strength safety factor requirements shall apply to all missions.

2. Consideration shall be given to transient loads and pressure, such as surge phenomena, when required.

3. Elongation criteria rather than the yield safety factors specified in Section 502 may be applied with the following restrictions:

   a. The structural integrity of the component affected shall be demonstrated by adequate analysis and test.

   b. There shall be no deformations which adversely affect the function of the component.

   c. The service life requirements of Chapters 6 and 7 shall be met.

   d. Use of this approach must be approved by MSFC.

4. In circumstances where pressure loads have a relieving or stabilizing effect on structural load capability, the minimum expected value of such loads shall be used and shall not be multiplied by the factor of safety in calculating the design yield or ultimate load. For example, the ultimate compressive load in pressurized vehicle tankage shall be calculated as follows:

   Ultimate Load = Safety Factor X Body Loads - Minimum Expected Pressure Load

5. Stress calculations of structural members, critical for stability and compressive strength, may be performed using the mean drawing thickness as the maximum thickness. The thickness used in the stress calculations for pressure vessels and for tension-critical and shear-critical members shall be the minimum thickness shown on the drawing.

501 HANDLING AND TRANSPORTATION FACTORS FOR FLIGHT STRUCTURES

The handling and transportation factors of safety for flight structures are the same as those given in Section 502. As a goal, flight structure design shall be based on flight loads and conditions rather than on transportation and handling loads. Transportation equipment design shall ensure that flight structures are not subjected to loads more severe than flight design conditions.

Transportation loads are a function of the transportation mode and shall include the steady state loads plus dynamic, vibration, and shock loads determined by analyses or tests.

502 SAFETY AND PRESSURE FACTORS

1. General Safety Factors for Metallic Flight Structures

	Yield	Ultimate	
Verified by Analysis Only	1.25	2.00	Chg. 1
Verified by Analysis and Static Test	1.10	1.40	

2. General Safety Factors for Non-Metallic Flight Structures

Verified by Analysis and Static Test

Non-Discontinuity Areas	1.4
Discontinuity Areas and Joints	*2.0

* Structural Test Factor = 1.4

3. General Safety Factor for Solid Propellants

Solid Propellant, Insulation, Liner, and Inhibitor	2.0

4. Safety Factors for Pressures

a. Propellant Tanks

**Manned

Proof Pressure = 1.05 x limit pressure
Yield Pressure = 1.10 x limit pressure
Ultimate Pressure = 1.40 x limit pressure

**Unmanned

Proof Pressure = 1.05 x limit pressure
Yield Pressure = 1.10 x limit pressure
Ultimate Pressure = 1.25 x limit pressure

b. Solid Motor Casings

**Proof Pressure	= 1.05 x limit pressure
Yield Pressure	= 1.20 x limit pressure
Ultimate Pressure	= 1.40 x limit pressure

c. Windows, Doors, Hatches, etc., Internal Pressure Only

Proof Pressure	= 2.00 x limit pressure
Ultimate Pressure	= 3.00 x limit pressure

d. Engine Structures and Components

**Proof Pressure	= 1.20 x limit pressure
Ultimate Pressure	= 1.50 x limit pressure

e. Hydraulic and Pneumatic Systems, including reservoirs

(1) Lines and Fittings, less than 1.5 inches (38 mm) diameter

Proof Pressure	= 2.0 x limit pressure
Ultimate Pressure	= 4.0 x limit pressure

(2) Lines and Fittings, 1.5 inches (38 mm) diameter or greater

Proof Pressure	= 1.2 x limit pressure
Ultimate Pressure	= 1.5 x limit pressure

(3) Reservoirs

Proof Pressure	= 1.5 x limit pressure
Ultimate Pressure	= 2.0 x limit pressure

(4) Actuating Cylinders, Valves, Filters, Switches

Proof Pressure	= 1.5 x limit pressure
Ultimate Pressure	= 2.0 x limit pressure

f. Personnel Compartments, Internal Pressure Only

Proof Pressure	= 1.50 x limit pressure
Yield Pressure	= 1.65 x limit pressure
Ultimate Pressure	= 2.00 x limit pressure

**Proof factor determined from fracture mechanics service life analysis must be used if greater than those shown.

CHAPTER 6. FRACTURE CONTROL AND FRACTURE MECHANICS ANALYSIS

600 GENERAL

All flight structures shall be examined to determine their fracture criticality and associated fracture control requirements. Pressure vessels and rotating machinery shall be considered fracture critical and therefore subject to fracture control. Other flight structures with failure modes that could cause loss of vehicle or crew shall be considered fracture critical candidates and undergo a fracture mechanics evaluation. The results of this evaluation will determine the remaining fracture critical parts to be placed under fracture control. See Figure 1 for fracture control selection logic.

All fracture critical parts shall have a fracture control plan establishing responsibilities, criteria, and procedures for the prevention of structural failures associated with the initiation and propagation of flaws or crack-like defects during fabrication, testing, handling and transportation, and operational life. This plan shall be generated in conjunction with MSFC and shall be developed during the preliminary design phase of all applicable components and maintained throughout the program. The fracture control plan should be developed based on the criteria in NASA SP 8095.

601 FRACTURE MECHANICS ANALYSIS AND PROOF TESTING

The fracture mechanics analysis and proof testing shall be performed using the following guidelines:

1. Fracture mechanics analysis shall be performed on all fracture critical parts to demonstrate that the maximum size flaw or crack-like defect that could exist after proof testing and nondestructive evaluation (NDE) inspection will not grow to critical size and cause premature failure during the required service life.

2. Proof testing, supplemented by NDE, shall be the preferred method for establishing the maximum size flaw or crack-like defect to be used in the service life analysis. However, when proof testing is not feasible, practical, or applicable, the NDE only method shall be acceptable with MSFC approval. Current state-of-the-art NDE inspection techniques shall be utilized. These requirements should be considered in the initial design phase of all applicable components; that is, the selection of materials, thicknesses, proof loading complexity, accessibility for inspection, ease of fabrication, etc.

3. All load sources and environments shall be considered in determining the appropriate loading spectrums for life analyses and proper application of flaw growth (da/dN) data. The best current state-of-the-art fracture mechanics analytical techniques shall be utilized.

4. The fracture mechanics analyses shall include the following factors:

   a. The analyses shall demonstrate a calculated life of 4.0 times the required service life.

   b. Stress concentration factors shall be included, when appropriate, in the mean and cyclic stresses.

   c. The proof test factor shall be the larger of the values determined by fracture mechanics analysis/proof test requirements to meet service life or those specified in Chapter 5 of this document.

   d. Proof testing shall be performed in the actual expected environment (temperature and media) when feasible. When this is not feasible, environmental correction factors shall be used to adjust the values in c. above.

   e. In no case shall the adjusted proof test factor be less than 1.05 without MSFC approval.

CHAPTER 7. FATIGUE

700 GENERAL

All structural components shall be evaluated for their capability to sustain cyclic load conditions which are part of the design environment. For those components whose design is subjected to a cyclic or repeated load condition, or a randomly varying load condition, fatigue analysis shall be performed.

701 FATIGUE ANALYSIS

The fatigue analysis shall be performed using the following guidelines:

1. A detailed design life cycle history shall be developed in sufficient detail that a cumulative damage assessment can be analytically verified for all applicable components. In general, these data can be shown by a component load history profile including usage cycles, load intensities, and environments.

2. For cyclic loads to varying levels, such standard methods as Miner's Method shall be used to determine the combined damage. For repeated load combined with a steady load, such standard methods as the Modified Goodman Diagram shall be used to determine the combined effect.

3. All structural elements shall be designed and analyzed to demonstrate the following factors:

    a. The limit stress/strain shall be multiplied by a minimum factor of 1.15 prior to entering the S-N design curve to determine the low cycle/high cycle life.

    b. The low cycle/high cycle fatigue analysis shall demonstrate a minimum calculated life of 4.0 times the required service life.

    c. The alternating and mean stress/strain shall include the effects of stress concentration factors when applicable.

4. All structural components subject to creep shall be assessed in the same manner as paragraphs 1, 2, and 3 above; that is, the applicable loads and associated histories shall be determined and the indicated factors applied for the creep life analysis.

5. All structural components subject to combined fatigue and creep shall be evaluated using such standard methods as Miner's accumulated damage procedure for final life predictions.

APPENDIX A: DESIGN INFORMATION DOCUMENTS

The following documents provide design information approved for use. The issue in effect on the date of the contract shall be used. Use of documents in addition to those listed shall have prior MSFC approval.

Military

MIL-HDBK-5	Metallic Materials and Elements for Aerospace Vehicle Structures
MIL-HDBK-17	Plastics for Flight Vehicles
MIL-HDBK-23	Structural Sandwich Composites
MIL-STD-1530	Fracture Control Guideline for Aircraft Structures

George C. Marshall Space Flight Center (MSFC)

NASA TMX-73305 NASA TMX-73306 NASA TMX-73307	MSFC Astronautics Structures Manual (3 Volumes)
--	MSFC Astronautics Design Manual
MSFC-STD-506	Material and Process Control
MSFC-SPEC-522A	Design Criteria for Controlling Stress Corrosion Cracking

NASA Space Vehicle Design Criteria Special Publications

SP-8025	Solid Rocket Motor Metal Cases
SP-8040	Fracture Control of Metallic Pressure Vessels
SP-8043	Design-Development Testing
SP-8044	Qualification Testing
SP-8045	Acceptance Testing
SP-8057	Structural Design Criteria Applicable to a Space Shuttle
SP-8082	Stress-Corrosion Cracking in Metals
SP-8083	Discontinuity Stresses in Metallic Pressure Vessels
SP-8095	Preliminary Criteria for the Fracture Control of Space Shuttle Structures

APPENDIX B: DEFINITIONS

The following definitions and terms shall be used for design and analysis of the stage or vehicle and in all documentation to establish uniform nomenclature with respect to loads, safety factors, fracture mechanics, fatigue, testing, etc.:

CDR - Critical Design Review

Flaws or Crack-Like Defects - Defects which behave like cracks that may be initiated during material production, fabrication, or testing or developed during the service life of a component.

Creep - A time-dependent deformation under load and thermal environments which results in cumulative, permanent deformation.

Critical Flaw Size - The flaw size which, for a given applied stress, causes unstable flaw propagation.

da/dN - The change in the flaw size for each load cycle.

DCR - Design Certification Review

Failure - A rupture, collapse, or seizure, an excessive wear, or any other phenomenon resulting in the inability of a structure to sustain loads, pressures, and environments.

Fatigue - In materials and structures, the cumulative irreversible damage incurred by the cyclic application of loads and environments. Fatigue can initiate cracking and cause degradation in the strength of materials and structures.

Fracture Control - The rigorous application of those branches of engineering, assurance management, manufacturing, and operations technology dealing with the understanding and prevention of flaw propagation leading to catastrophic failure.

Fracture Control Plan - A plan which controls those parts identified as fracture critical. This plan is directed toward preventing catastrophic structural damage associated with flaws or crack-like defects during fabrication, acceptance testing, or operational service.

Fracture Critical Part - A part which, by fracture mechanics analysis, has a service life factor of less than 4.0 times the vehicle life cycle requirements and failure of which would cause loss of the vehicle or crew. Also, a part that is a pressure vessel or a rotating machinery component. (see Figure 1).

Fracture Mechanics - An engineering discipline which relates the influence of loading, geometry, material parameters, and environment on the fracture of a material caused by flaw propagation from initial flaws or crack-like defects.

FRR - Flight Readiness Review.

Initial Flaw Size - The maximum size flaw, as defined by proof test or nondestructive inspection, which could exist in parts without failure in proof test or detection in NDE. (Also initial critical flaw size.)

Load Spectrum - A representative of the cumulative static and dynamic loadings anticipated for a structural component or assembly under all expected operating environments.

NDE - Nondestructive Evaluation

Non-Safety Critical Structures - Structures not causing loss of vehicle or crew if they fail.

PDR - Preliminary Design Review.

Pressure Vessel - A component designed primarily for the storage of pressurized gases or liquids.

Proof Load or Pressure - The product of the maximum limit load or pressure and the proof factor.

Proof Test - The test of a flight structure at proof load or pressure which will give evidence of satisfactory workmanship and material quality or will establish the initial flaw size prior to acceptance of the structure for flight.

Protoflight Structure - An actual flight structure.

Protoflight Test - A test performed on a protoflight structure.

Qualification Tests - Tests conducted on flight-quality structures at load levels to demonstrate that all structural design requirements have been achieved.

Quasi-Static Load - A time-varying load in which the duration, direction, and magnitude are significant, but the rate of change in direction or magnitude and the dynamic response of the structure are not significant.

Random Vibration - The rapid back and forth haphazard motion of a structure caused by acoustical and/or mechanical forcing functions.

Rotating Machinery - Machinery which has rotating parts.

Safety Factors - Factors multiplied times limit loads or stresses to establish higher design loads or stresses for strength analyses to assure structural integrity of structures.

Safety Margins - The percentage by which the failure load or stress exceeds the limit load or stress that has been multiplied by the safety factor.

Service Life - The interval beginning with manufacture of a vehicle and ending with completion of its specified missions.

Special NDE - NDE which exceeds normal state-of-the-art NDE in flaw or or crack-like defect detection by using special techniques and equipment.

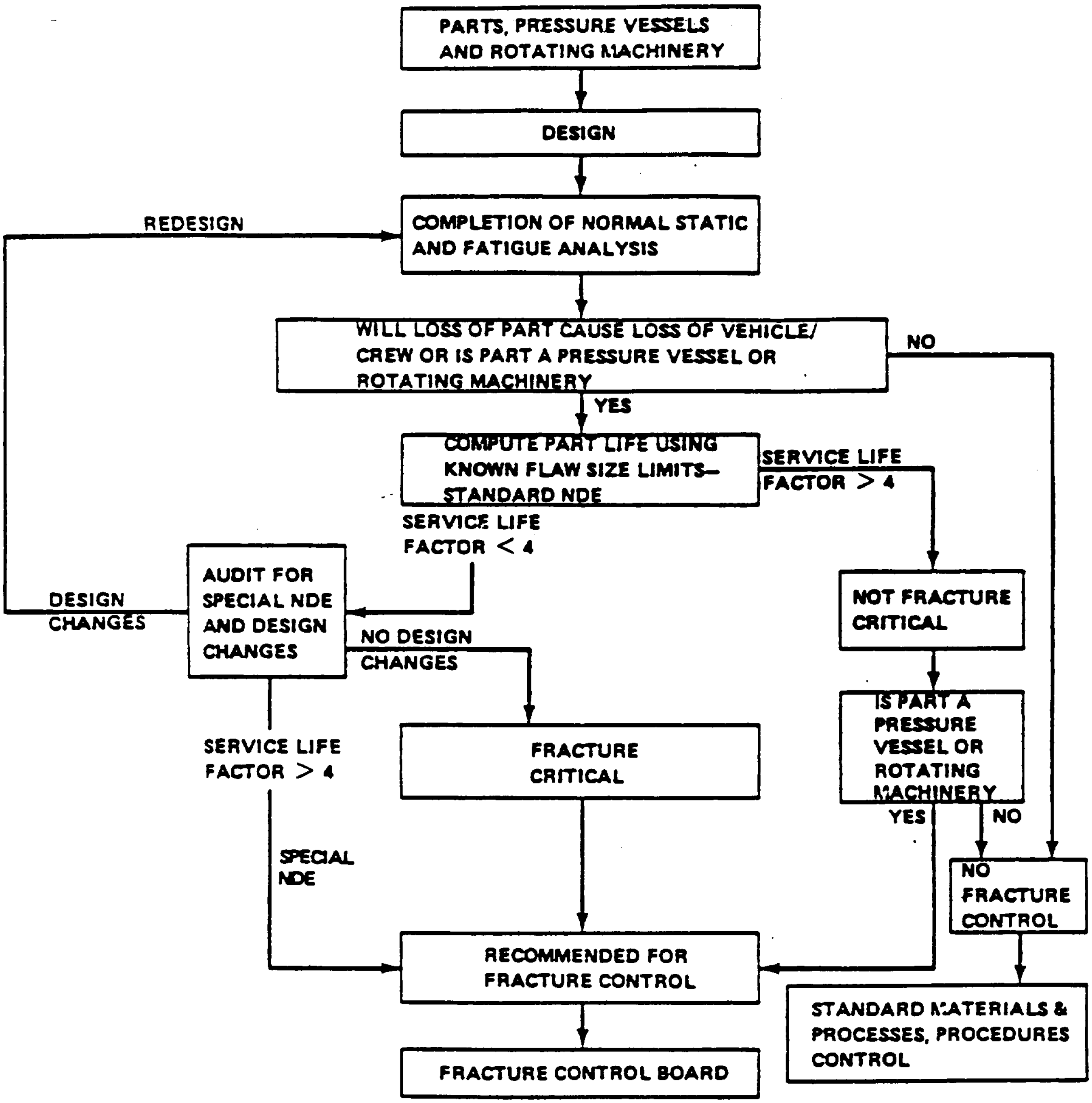
Static Load - A load of constant magnitude and direction with respect to the structure.

Structural Integrity - The ability of a structure to comply with the specified design requirements.

Ultimate Pressure or Load - The pressure or load at which an unflawed structure should fail if all the sizing allowables (material strength, thickness, etc.) are at their minimum specified values.

Ultimate Strength - Corresponds to the maximum load or stress that a structure or material can withstand without incurring rupture or collapse.

Yield Strength - Corresponds to the maximum load or stress that a structure or material can withstand without incurring detrimental deformation.



NOTE: SERVICE LIFE FACTORS ARE BASED ON TYPICAL MATERIAL PROPERTIES.

FIGURE 1. FRACTURE CONTROL SELECTION LOGIC